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DESIGN DIVISION

DEPARTMENT OF
MECHANICAL ENGINEERING

STANFORD UNIVERSITY

STANFORD, CALIFORNIA

MECHANICAL DESIGN ANALYSIS

OF BIOLOGICAL INSTRUMENTATION

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INTRODUCTION

In October, 1962, the Jet Propulsion Laboratory funded a program at Stanford University for a study entitled Mechanical Design Analysis of Biological Instrumentation. The primary object of the proposed study was to provide mechanical engineering analysis and design support for Stanford's Exobiology program in the Genetics Department, School of Medicine, under the direction of Dr. Joshua Lederberg. Ancillary efforts were to be directed at the general area of micro-miniaturization of mechanical devices with particular attention paid to energy-storage devices and ingenious mechanisms. The major concern of the program was to demonstrate the feasibility of producing a life detection instrument suitable for space application based on the use of a fluorogenic indicator for the detection of enzymes characteristically produced by soil microbes. The instrument making use of the enzyme detection principle is known as the Mark II Multivator.

The instrument consists of twelve reaction chambers into which a stream of dust-laden air is introduced and three dummy chambers for control purposes. In operation a sample of dust is deposited in the reaction chambers whereupon the chambers are sealed and solvent is injected. A pellet of chemicals which has been stored in each reaction chamber dissolves. The pellet, also called the "substrate", contains a flourescent compound and a flourescence inhibitor upon which the enzymes act. The reaction begins and after some minutes, flourescent excitation lamps at each chamber are turned on one at a time. A photomultiplier tube detects the flourescent light intensity in each chamber. The resulting signal is then digitized and transmitted to Earth. An advanced model of the Mark II Multivator is shown in Figure 1.

Basic areas investigated include:

1. The storage, transfer, and valving of solvents used in the biochemical experiments.
2. Means for distributing dust samples to the various test chambers in the instrument.

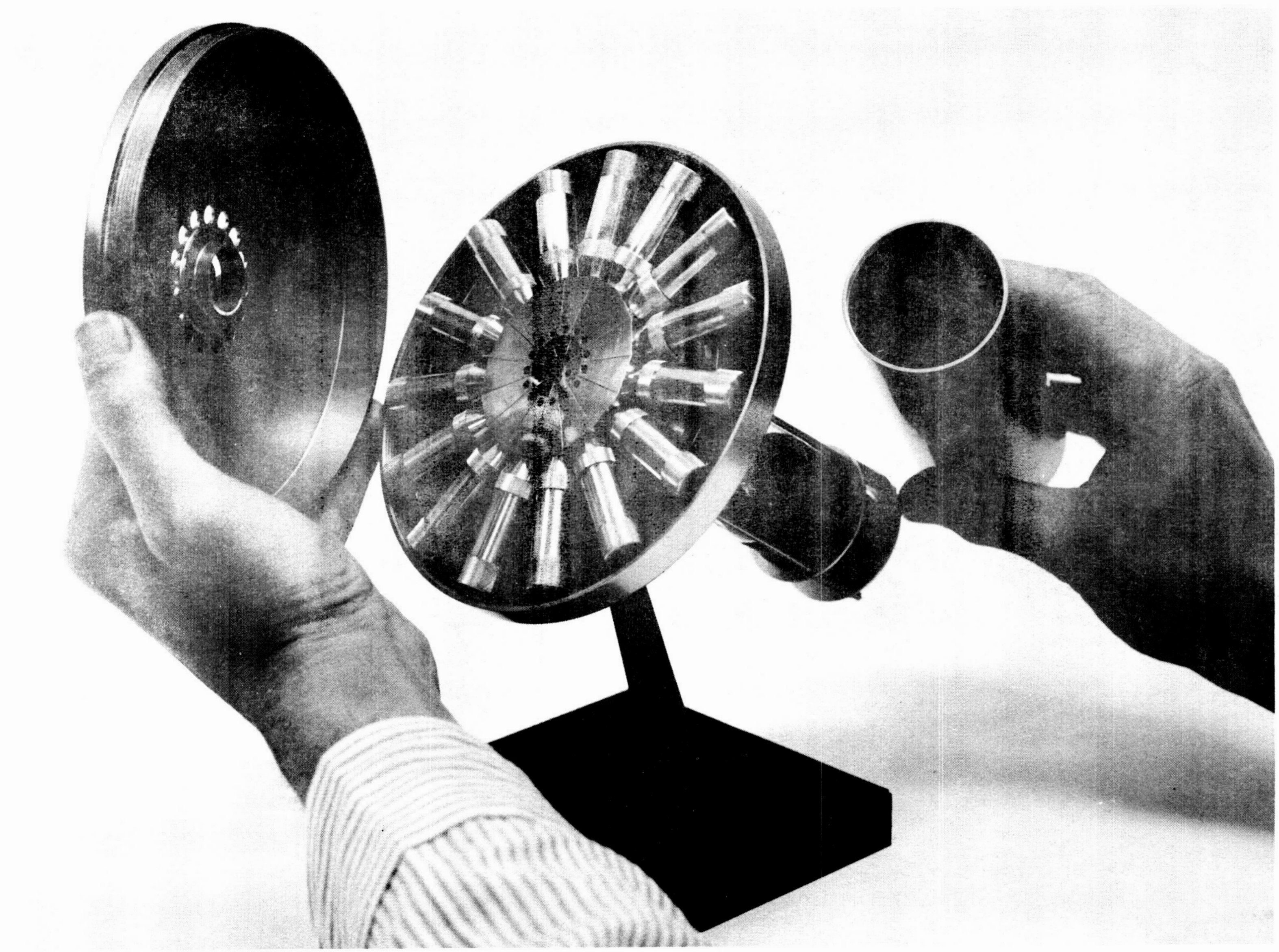

FIGURE 1. MARK II MULTIVATOR, CONCEPT 3,
HOUSING PARTIALLY REMOVED

3. Sealing the test chambers from the Martian atmosphere.
4. High efficiency energy storage and conversion as related to the actuation of mechanisms.

The experience acquired during the study of these problem areas has resulted in three separate monographs not included with this report (1)*, (2), (3). These monographs deal with electroexplosive devices, energy storage in small batteries, and recent advances in mechanisms. They resulted from literature studies conducted to determine the state-of-the-art in areas related to the design of the Mark II Multivator and other life-detection instrumentation. In addition, a study of small motors was undertaken, but we were unable to identify sufficient quantitative information in this specialized area to compile a meaningful monograph. The electroexplosive device monograph (1) qualitatively discusses such factors as power-to-weight, power-to-size ratios, functioning time, construction, and triggering. Typical of such devices is the bellows motor, which produces force and motion during the combustion of an explosive charge confined in an extensible casing. The small battery monograph (2) discusses commercially available, high performance batteries weighing less than four ounces. They are compared to obtain their relative energy storage densities on a weight and volume basis. In the third monograph (3), on mechanisms, a large number of devices are described and illustrated, including toggle-spring mechanisms, clutches, couplings, latches, cams, and cycling mechanisms.

This report primarily outlines the design and evaluation of the Mark II Multivator. Problem areas encountered in the design of the Mark II Multivator are described. Plans for future work on the Mark II Multivator to be continued under NASA sponsorship, are discussed.

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* Numbers in parentheses refer to references in the Bibliography.

DESIGN CRITERIA FOR THE MARK II MULTIVATOR

The primary goal of the Mark II Multivator program was to design an instrument with the lowest practicable weight and power consumption, capable of withstanding heat sterilization, six months of flight through hard space, and the shock of launch and landing. Once on Mars, the instrument must tolerate exposure to temperatures ranging from -120° to +30°C. and operate reliably in a temperature-conditioned ambient of approximately 20°C. with an atmospheric pressure of 10 to 100 millibars.

During the early stages of the program, the Multivator was envisioned to include both a dust pick up device and a miniature analysis laboratory. However, by December 1963, the program had advanced to the point where it now seemed desirable to have a more flexible system, namely one that could use a number of different types of pick up devices as well as various sample preparation techniques. In a meeting at Stanford on December 18, 1963, attended by representatives of Stanford University, Litton Industries, and the Jet Propulsion Laboratory it was decided to change the Mark II Multivator to an analysis instrument only. Accordingly, the design was revised to accommodate the aerosol provided by sample collection and preparation devices located elsewhere in the life-detection system. Concept 3 of the Mark II Multivator, described in detail later in this report, contains all the mechanism and circuitry necessary to detect life, and has a port to receive a sample delivered from an external aerosol generator.

The mechanical design constraints were as follows:

1. Number of test chambers 12
2. Number of control chambers 3
3. Chamber volume . . . . 0.001 in^3
4. Instrument volume . . . . less than 50 in^3
5. Weight . . . . less than 2 lbs.
6. Power . . . . less than 1/2 watt
   (For mechanisms operation only; not including electronics)
7. Aerosol stream . . . . 10 cfm at 0.5 psia with dust density of 0.5 grams/$ft.^3$
8. Dust particle characteristics . . . . density of 1 to 2, with size range of 10 to 100 microns diam.
9. Sample size . . . . 10 milligrams per chamber

Particular consideration was given to the possibility of volumetric changes in the solvent storage chambers during exposure to temperature extremes. For example, the solvent storage chambers of Concept 3 contain a piece of air-filled, closed-cell foam material to accommodate changes in liquid volume.

Sterilization of the instrument is presently planned as a two-step operation. First the Multivator, less substrate, will be sterilized by heating to 135°C. for 36 hours. The substrates, sterile as a result of production under sterile conditions, are next installed in the instrument in a sterile assembly box. Consideration is also being given to the possibility of using ethylene oxide gas for sterilization of the instrument.

MARK II MULTIVATOR, CONCEPT 1

The Model II Multivator, Concept 1, shown in Figure 2, uses deformable and frangible diaphragms for valving operations, an electrically triggered explosive charge for valve actuation and solvent injection, and a metal bellows for storing solvent.

Detailed Description and Operation

This concept consists of 15 reaction chambers arranged in a circle surrounding a central valving manifold, shown schematically in Figure 3. The aerosol enters and exits the reaction chambers through the manifold area following the path indicated by the arrows. While passing through the reaction chamber, the aerosol stream is greatly reduced in velocity as it swirls around the walls of the chamber. The combined effects of the reduced velocity and swirling aerosol stream bring the dust particles out of suspension against the chamber walls. The walls, which have been coated with a sticky substance, collect these particles while the air continues out of the chamber.

After a sample has been collected in the chambers, an explosive charge is fired which is located between the two metal diaphragms placed respectively on each side of the entrance and exit manifold. The entrance and exit to each chamber are sealed by the diaphragm expansion, isolating the chambers from one another as shown in Figure 4, stage 5.

Next, solvent is introduced into each chamber from a common solvent container located above the chambers, as shown in Figure 3. During previous stages of operation and space flight, the solvent has been isolated in its donut-like container by a foil membrane which blocks the passages leading to the reaction chambers. During solvent injection, an explosive charge above the solvent container forces pins attached to the upper cap through the membrane. Further motion of the upper cap forces solvent into the chamber until it bottoms against the lower cap and seals all 15 chambers. The mechanical operations are then complete and a period of incubation followed by observation ensues.

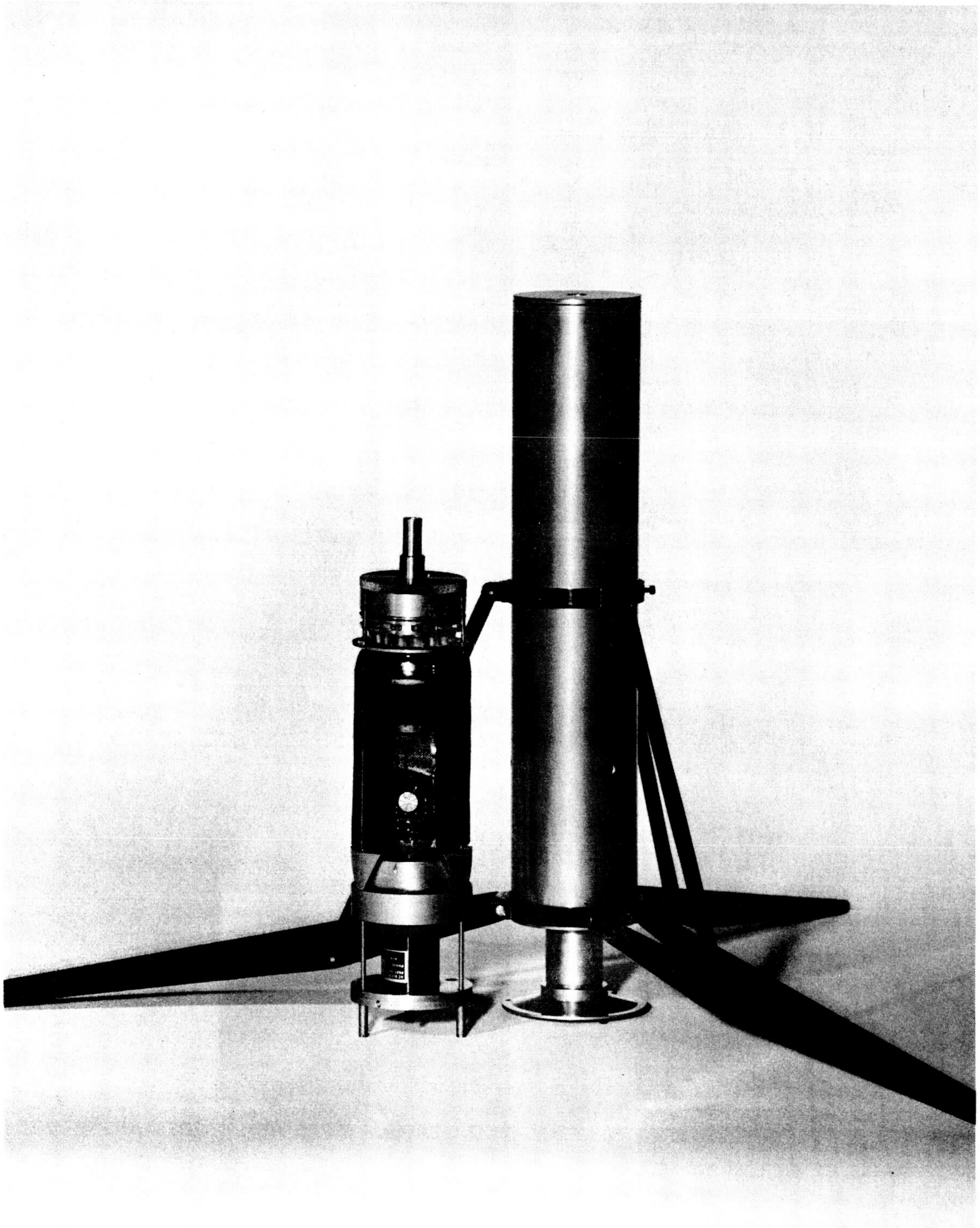


FIGURE 2. MARK II MULTIVATOR, CONCEPT 1, INTERNAL MECHANISM AND PHOTOMULTIPLIER REMOVED FROM CASE.

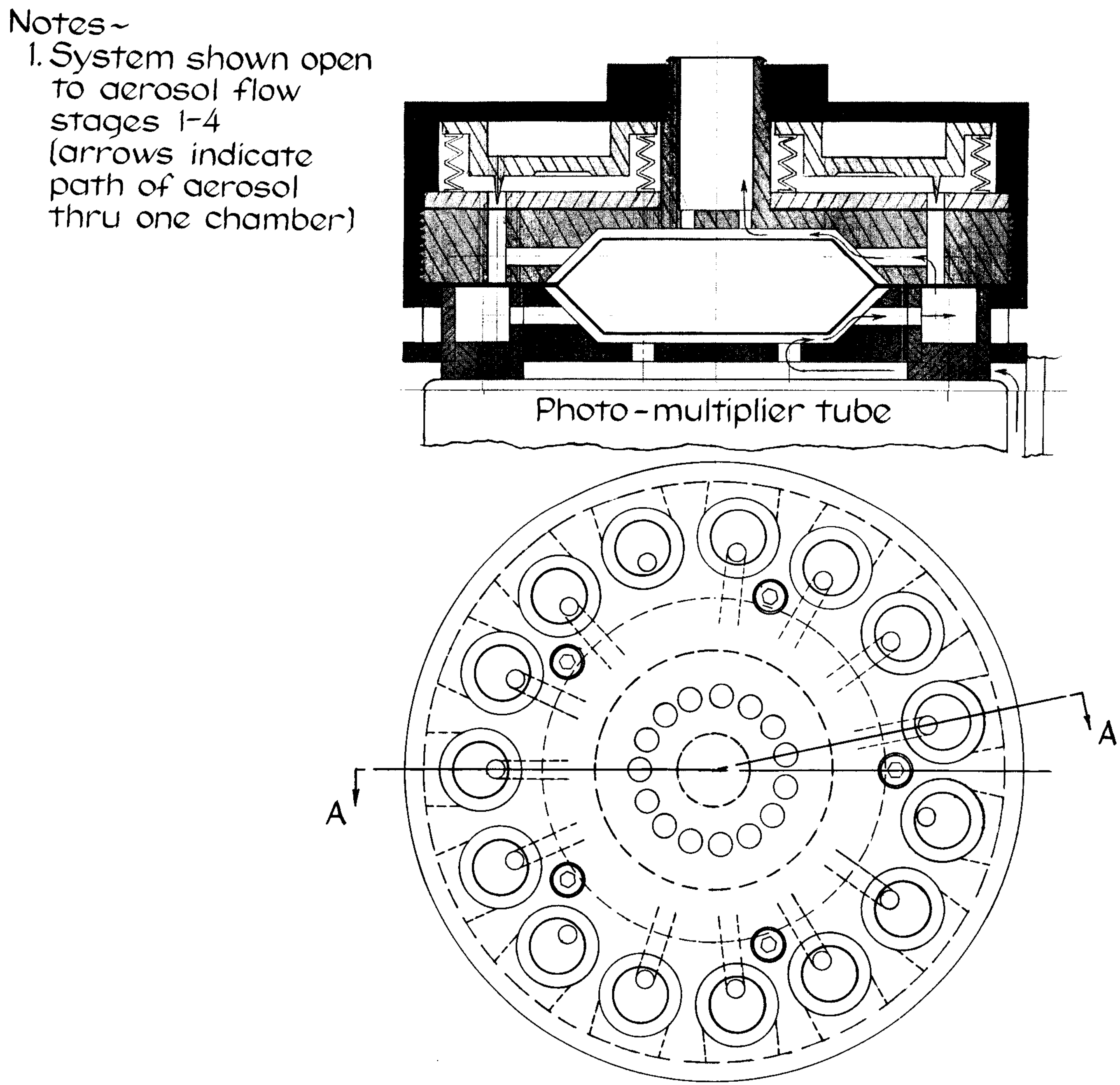
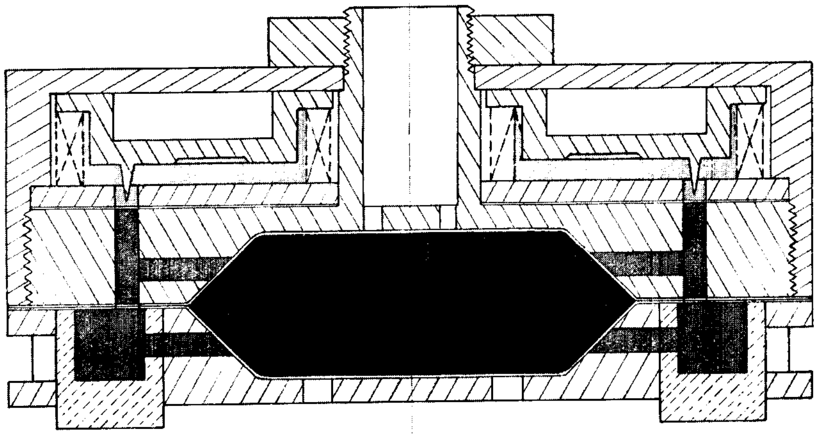
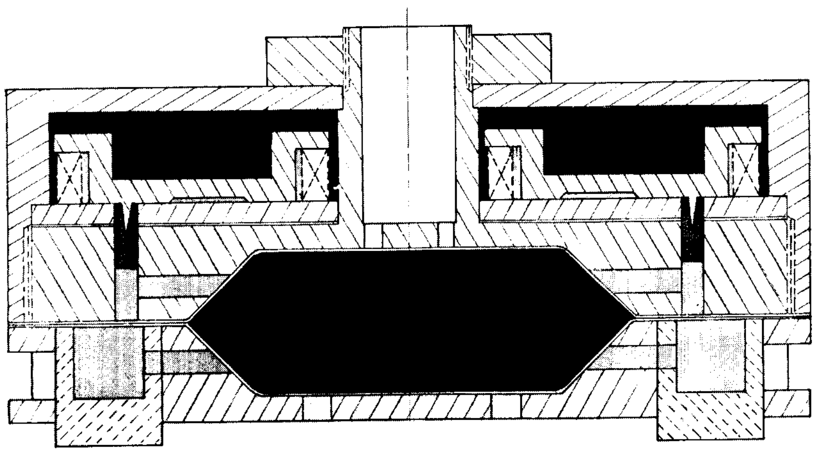


FIGURE 3. REACTION CHAMBER CROSS SECTION
ANC CIRCULAR CHAMBER ARRANGEMENT



Stage #5
Aerosol passages sealed



Stages #6-8
Aerosol passages sealed~solvent injected

Sequence of events

Stage	Description
1	Eject from capsule
2	Erect on legs
3	Start collection pump
4	Pump air & dust thru chambers
5	Fire valve squib & seal air passages
6	Fire solvent & fill chambers
7	Incubate
8	Turn on lights sequentially & note results

FIGURE 4. CONCEPT 1, POSITION OF PARTS DURING OPERATIONAL SEQUENCE

With this concept, the substrate necessary for the bio-chemical reactions could either be located in the sticky material on the chamber walls or in the passageway leading from the solvent container to the chambers. The latter method would allow dry storage, the substrate being kept between two foil membrances which burst upon solvent injection.

There are two windows in each reaction chamber positioned perpendicularly to each other as shown in Figure 3. Filtered light from a light source enters the side window and illuminates the solution in the reaction chamber. Flourescent light emmanating from the solution passes through the window in front of the photomultiplier. The exit window has a filter which transmits light only at the wavelength of the flourescent light. In this manner, reflected light from the primary light source is prevented from reaching the photomultiplier.

Advantages and Disadvantages of Concept 1.

The major advantage of Concept 1 is its small size and light weight. Additionally, it contains no parts which slide or move over each other during any phase of operation. All motions occurring involve deformations of thin-walled elements in the device.

The valving mechanism in the area where dusty and gritty material passes is a soft, deformable material. This is advantageous since the valve can form over bits of dust and still seal.

A major disadvantage to this design is that it requires a residual gas pressure to maintain a seal. This means that the two areas in which squibs are fired must be absolutely gas tight. Tests showed two ways in which gas pressure could be lost. The first was from gas escaping through the juncture between the two diaphragms. The second mechanism causing a loss in residual gas pressure was the cooling of the gases from combustion temperature to environmental temperature. Malfunctioning in the seal area was considered particularly detrimental because any leakage of gases or liquids could contaminate the Martian environment.

Another disadvantage of Concept 1 was its circuitous aerosol passageway. This resulted from both desiring the photomultiplier tube to view the sample reaction chamber through the bottom of the test chamber, and desiring a symmetrical path for transport of test particles from the Martian surface to the reaction chambers. There are several bends and changes in cross-sectional area where portions of the sample may drop out of suspension before reaching the chambers. These bends also cause high flow resistance which increases the power requirements for the aerosol generator.

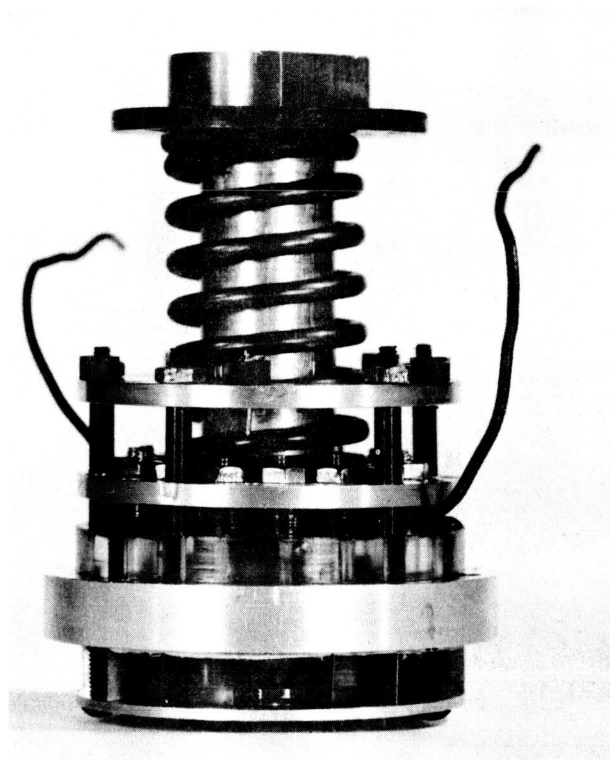


FIGURE 5. CONCEPT 2, SPRING ACTUATED VALVING WITH BELLOWS SOLVENT STORAGE

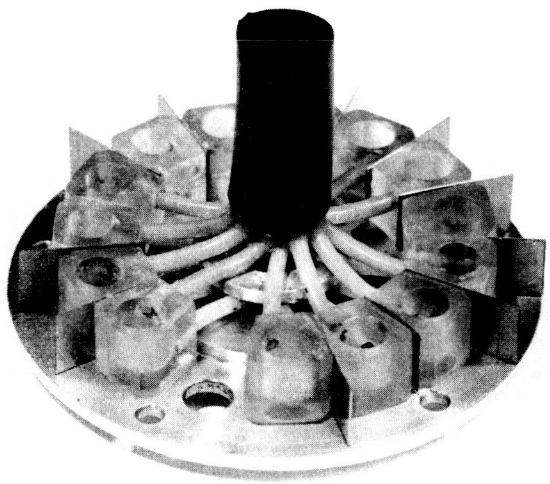


FIGURE 6. CONCEPT 2, ENTRANCE AND EXIT HOSES ATTACHED TO REACTION CHAMBERS

MARK II MULTIVATOR, CONCEPT 2

The Concept 2 Multivator, shown in Figure 5, uses electrically-released, compressed springs as an energy source, pinchable tubes for valving, and individual bellows for storing solvent. The solvent is sealed in each bellows by a frangible diaphragm.

Detailed Description and Operation

Concept 2 has basically the same circular reaction chamber arrangement as Concept 1. The aerosol enters through a flexible tube, passes through the chamber depositing dust on the sticky chamber walls, and continues out the other flexible tube.

The reaction chambers are individual units with tubes cast integrally into the wall, as shown in Figure 6. The hoses are located at opposing positions in the reaction chambers, causing the aerosol to swirl along the walls as it passes through the chamber. The entrance hoses are clustered into a bundle and inserted into a common aerosol supply hose. The exit hoses are very short to reduce air flow resistance.

Concept 2 is spring-powered, the springs being compressed at assembly. The springs are held in the compressed position by lengths of high-resistance nichrome wire. When it is necessary to either close the aerosol passages or inject the solvent, an electric current is passed through the appropriate set of wires, causing them to heat, yield, and release the compressed spring which performs the mechanical operation desired.

There are two springs in Concept 2, which provide energy for valving and solvent injection. One spring is visible in Figure 5. The other spring is located within the vertical aluminum tube inside the first spring. When the inner spring is released, it drives a plunger down which collapses and seals the hoses leading to and from each reaction chamber. The outer spring acts against a ring to which are attached 15 small bellows that serve as individual solvent containers for the 15 reaction chambers. When the outer spring is released, the hydrostatic pressure generated in each bellows ruptures a foil membrane sealing the solvent from the chamber. As the solvent fills the chamber, it compresses the air in the chamber into a tiny bubble. The individual bellows keep the reaction chambers independent and isolated from each other at all times during solvent injection.

Advantages and Disadvantages of Concept 2

The Concept 2 design eliminated the need to maintain a residual gas pressure for sealing. Instead, springs provide a steady, predictable, sealing force. Also, hoses of constant diameter conduct the aerosol stream directly into the chambers, thus eliminating a tortuous path. Each reaction chamber has its own solvent container, making possible a different solvent for each chamber.

A disadvantage is the high pressure loss through the tubes leading to the chambers. The physical size of the chamber limits the diameter of circular hose which can be put into a chamber. However, the pressure loss could be somewhat reduced by extruding special hoses of rectangular cross-section having a larger area than the circular hose presently used.

Another disadvantage is that the nichrome wire triggering scheme requires excessive power compared to schemes using squibs or fusible links.

MARK II MULTIVATOR, CONCEPT 3

Concept 3 is a culmination of the experience gained on Concepts 1 and 2, studies regarding the problem of air bubbles in the reaction chambers, and the decision mentioned earlier, which required that the Multivator be an analysis instrument only. Concept 3 eliminates the most objectionable features of Concepts 1 and 2, in particular, unreliable sealing, the possibility of contaminating the environment in the event of operational failure, and the possibility of cross-contamination of reaction chambers. The modularized design of Concept 3 adds system redundancy thereby increasing reliability and probability of mission success. Furthermore, its total volume is only 42 in^3, weight less than 1.4 lbs., with a power requirement under one-half watt.

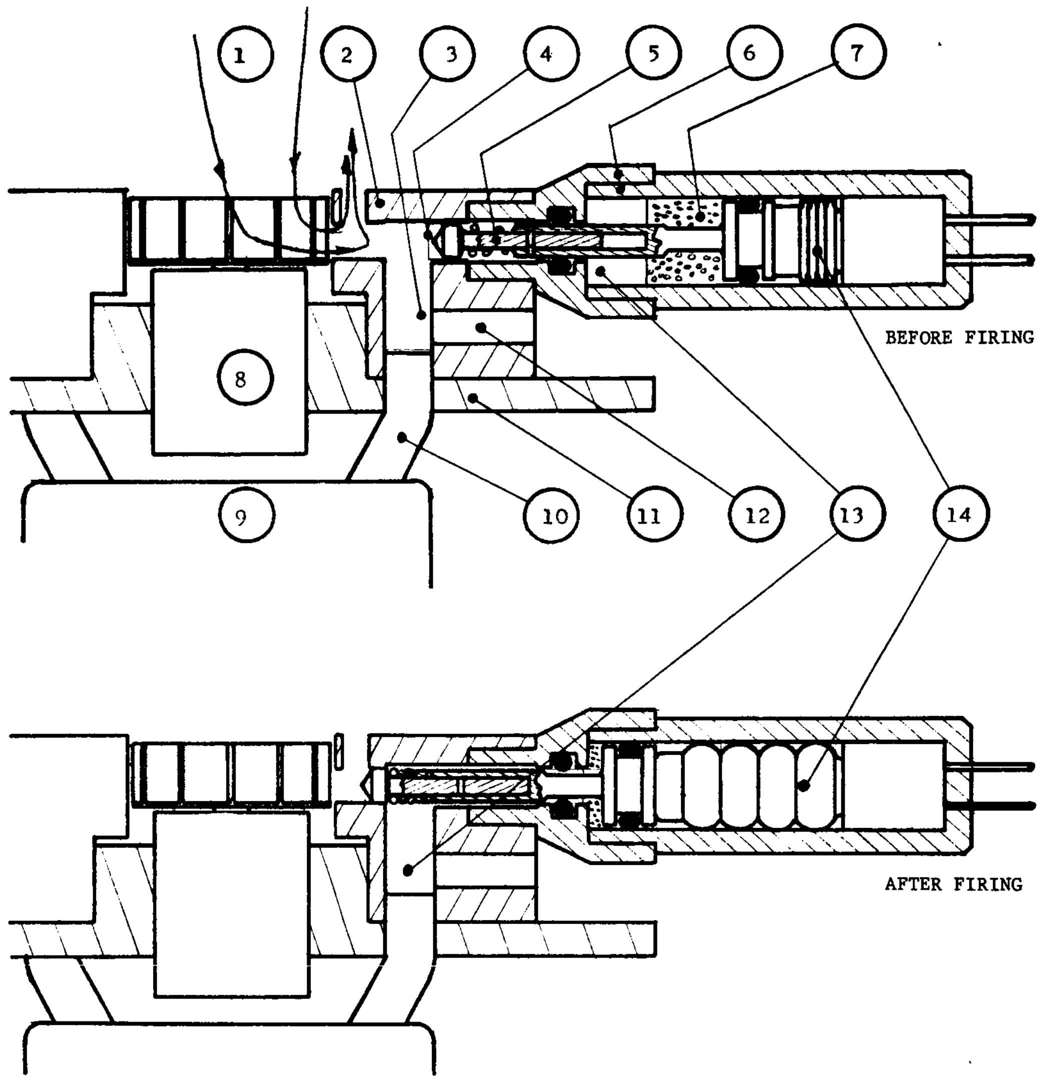
The distinctive features of Concept 3 include a modularized reaction chamber assembly, explosive-charge bellows motors for valve actuation and solvent injection, and a motor-driven centrifugal dust separator. The reaction chamber assembly, the housing enclosing the reaction chambers, the photomultiplier, and electronics are shown in Figure 1.

Detailed Description and Operation

Concept 3 consists of 15 modules arranged in a circular pattern, with an impeller in the center as shown in Figure 1. Each of the modules consists of a reaction chamber, solvent storage chamber, tapered valve pin, explosive-charge bellows motor, and light source, as shown in Figure 7.

In operation, dust-bearing air is drawn through the impeller and in front of the reaction chambers. The impeller impacts particles into the reaction chambers where they settle or are captured by a sticky coating. Upon completion of the particle collecting operation, the bellows motors are electrically triggered. Expansion of the bellows results in sealing of the reaction chambers and injection of the solvent.

The injection and valving mechanism operates as follows: The tapered valve stem telescopes into the piston shaft as shown in Figure 7. A partially compressed coil spring is mounted on the valve stem. A shear



1	Aerosol Input	8	Motor-Impeller Assemble
2	Reaction Chamber Block	9	Photomultiplier Tube
3	Reaction Chamber	10	Light Pipe
4	Diaphragm	11	Mounting Bracket
5	Valve Stem,Piston,Shear Pin,Spring	12	Excitation Lamp
6	Injection-Valving Unit Housing	13	Solvent, Pre & Post Actuation
7	Foam Displacement Pad	14	Bellows Motor,Pre & Post Actuation

FIGURE 7. CONCEPT 3, MODULE CROSS-SECTION

pin holds the stem in the piston shaft. The piston shaft is stepped so that during the initial part of the stroke, no solvent can flow past the stationary "O" ring seal. A piece of air-filled, closed-cell, elastic foam is located between the solvent and piston. The entire solvent chamber is sealed prior to operation by means of a thin diaphragm placed in front of the pointed valve tip. This seal is necessary to contain the water during sterilization and space flight and is ruptured by the valving mechanism during solvent injection.

Upon firing the bellows motor, the piston compresses the foam while the valve tip pierces the diaphragm. When the valve is seated, the shear pin breaks, permitting the piston to continue to move while the valve remains seated due to the force exerted by the spring. When the step on the piston shaft passes the "O" ring seal, solvent flows into the reaction chamber due to the air pressure previously established in the compressed foam. The piston continues to move until the reaction chamber is filled with solvent. The air trapped in the reaction chamber immediately after valve closure is reduced to a small bubble due to relatively high solvent injection pressures. The closed position of the valve can be seen in Figure 7. The valve is held in the closed position by means of a residual force supplied by the expanded bellows.

The closed-cell foam is compressible, which permits the piston to move while solvent remains confined in the reaction chamber. The closed-cells of the foam also prevent any air bubbles from being injected into the reaction chamber. The compressibility of the foam permits expansion of the solvent due to possible freezing or while the module is subjected to high sterilization temperatures.

Technical Discussion

Dust Separation

The Multivator package is provided with a stream of air containing dust particles in suspension. The problem is how to remove the particles from the air and deposit them with uniform quantity and particle size distribution in each of 12 reaction chambers. Specifically, the particles have a size range from 10 to 100 microns diameter, density of 1 to 2, and are obtained from a 10 cfm. aerosol stream at 0.5 psia Martian atmospheric pressure.

A type of centrifugal dust separator was designed which makes use of a motor-driven impeller that imparts radial velocity to the air-borne dust particles. The reaction chambers are arranged around the impeller, which is the vaned structure in the center of the Multivator module array shown in Figure 1. Air passes through the impeller and out the exit port, as shown in Figure 7. Dust particles acquire sufficient momentum from the impeller, which turns at about 15,000 rpm, to carry them into the reaction chamber where they either settle due to stagnation conditions or are retained by a sticky coating on the chamber wall.

The dust separator has been tested using the lucite reaction chamber assembly shown in Figure 8. In this test assembly, the inlet hole was bored through the wall of the reaction chamber farthest away from the impeller. During the tests, a strip of black adhesive tape was wrapped around the lucite ring, sealing the opening in the reaction chamber walls. The sticky coating of the tape captured talcum powder particles that were used to give a qualitative indication of dust collection effectiveness. A strip of tape produced during dust collection tests is shown in Figure 8.

Impeller Drive Motor Selection

A search was made for an impeller drive motor with input power of 1/2 to 1 watt, a peak efficiency of 30% or more, and a speed of 10,000 rpm or more. Information was gathered on a.c. motors, and d.c. motors with and without brushes.

The a.c. motors were considered because they potentially have greater reliability than d.c. motors if the latter use brushes. The life of an a.c. motor, for example, is limited primarily by its bearings. However, a.c. motors require an inverter in order to operate from a battery power supply which lowers the overall power conversion efficiency, and small a.c. motors are typically not very efficient. Stock motors in the frame size and power output range of interest were not located, however, a consulting firm was located with the capability of custom

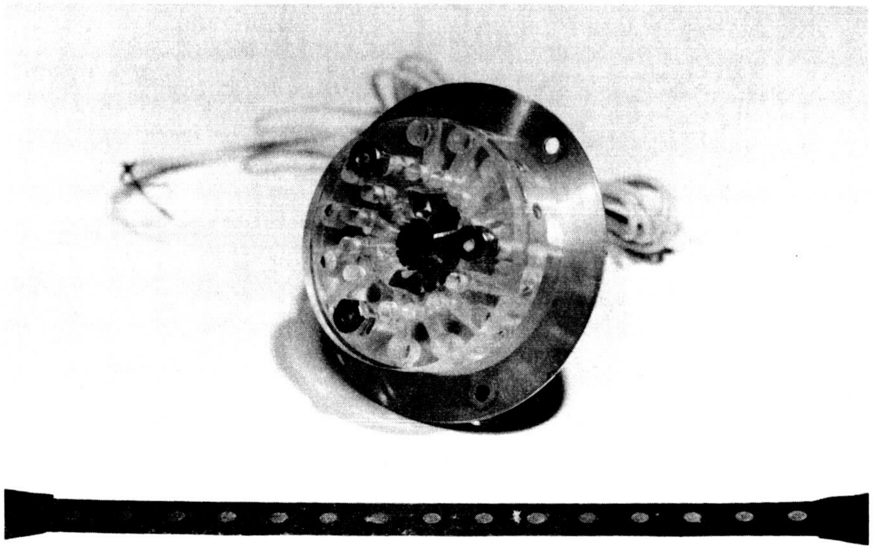


FIGURE 8. TEST MODEL OF IMPELLER DUST COLLECTOR

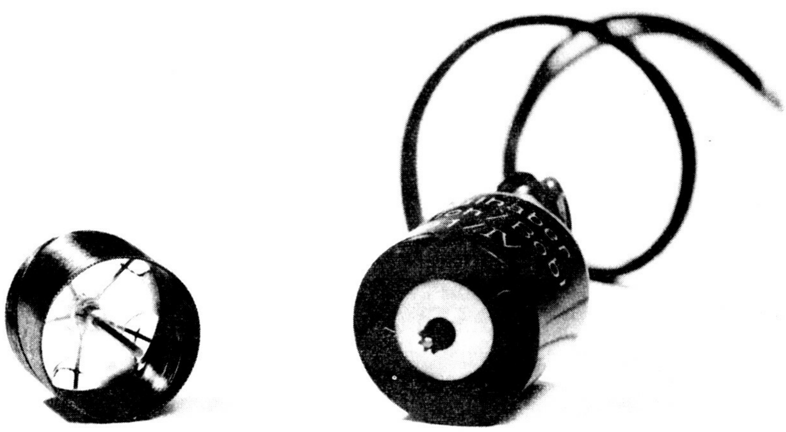


FIGURE 9. MINIATURE MOTOR, THE MICRO-MO

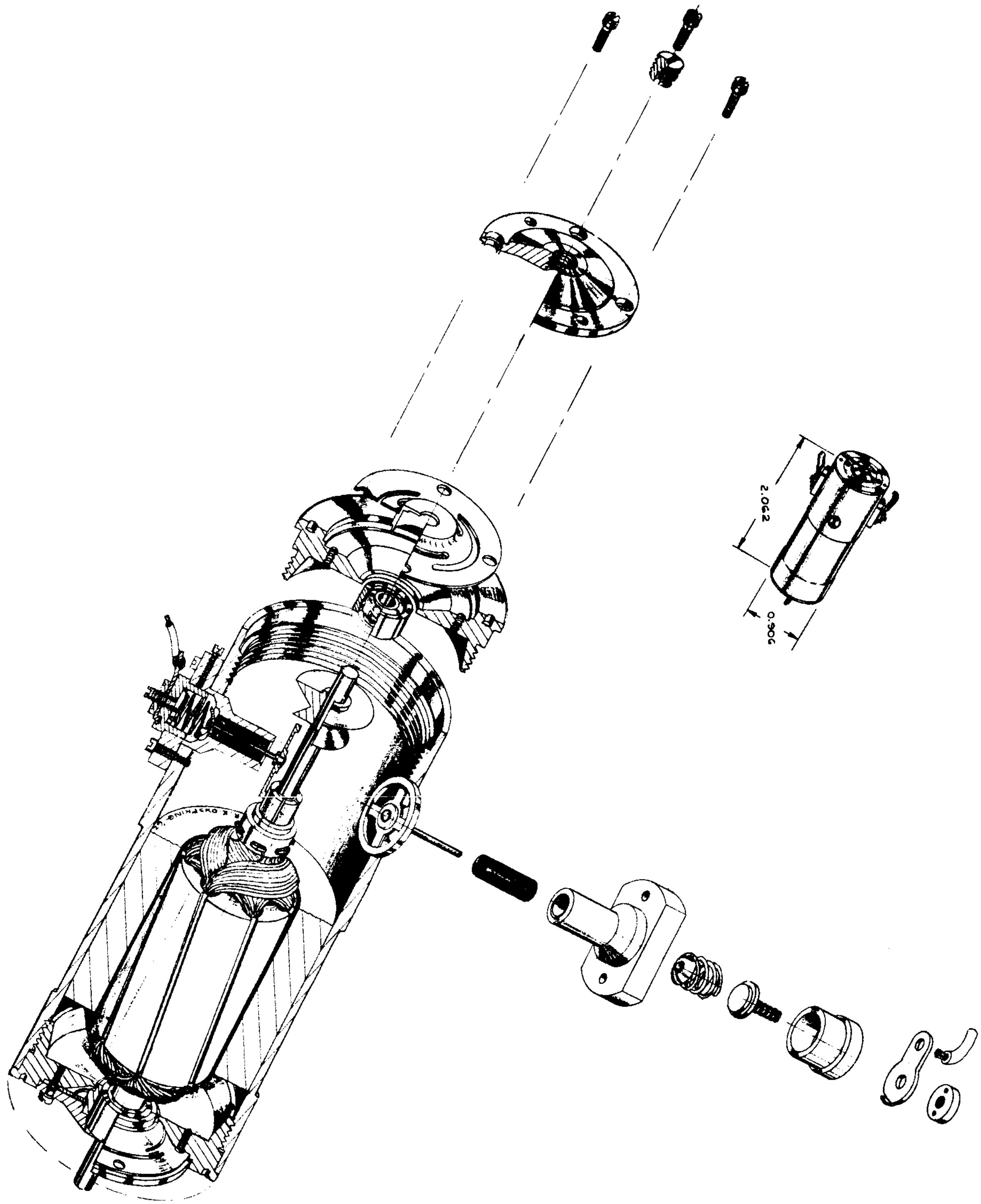


FIGURE 10. MINIATURE MOTOR BY JAPAN MICROMOTORS, INC.

designing a motor to suit our requirements.

Conventional d.c. motors were more promising from the standpoint of availability. Two d.c. motors were located which appear to be suitable for the present application. Both motors require less than 1 watt power input, have efficiencies better than 40%, and use metal brushes. One motor, called the "Micro-Mo" is made in Germany. This motor, shown in Figure 9, works in a manner similar to that of a D'Arsonval meter movement. The rotor, which has the shape of a thin-walled cup, contains no iron and consists almost entirely of copper wires bonded together to form a single structure. Each of the two brush assemblies consist of several strips of small diameter wire clamped together.

The other motor is made in Japan by Japan Micromotors. This motor, shown in Figure 10, uses metal brushes which rotate on the commutator surface with very little sliding. As a result, motors using these brushes basically have efficiencies better than 60% with power input in the range of 1/2 to 1 watt. These motors are precisely made and have been used to drive satellite-borne instruments.

The Japanese and German motors previously described apparently do not have counterparts manufactured in the United States. Miniature, American-made d.c. motors of high quality are neither small enough nor efficient enough for our purposes.

The possible detrimental effect of a rarefied Martian atmosphere and many months of storage in a space vacuum on brush performance remains to be determined. Since the motor operates only for a few minutes in this application, the effect of a rarefied atmosphere may not be significant. Many tests of the dust collection system have been made in a rarefied atmosphere with no apparent harm to the d.c. motor used.

The problem of brush wear could be by-passed by using a brushless d.c. motor. Motors of this type are not readily available in small sizes, and would probably not offer any greater efficiency than an a.c. motor.

Bellows Motors

An explosive charge bellows motor is used for operating the valve and solvent injection piston in each module. The particular bellows motors used is a Hercules Powder Company Type BA31K7, which provides a 20 lb. force over a 3/8 inch stroke. The device is electrically triggered by applying a 5 volt, 1 ampere, pulse for 0.6 milliseconds. The energy required for triggering is 3 milli-watt seconds. The unit is sealed and manufacturers' data indicate that it can be subjected to vacuum and temperature extremes and perform reliably.

Valving

In all concepts considered for the Mark II Multivator, a system of valving and sealing is required to accomplish the following, in order as they occur:

1. Hold a substrate solvent supply captive during the six months journey between Earth and Mars.
2. Leave the twelve test chambers "open" to receive dust samples from the surface of Mars.
3. Seal off the test chambers from each other and from the Mars atmosphere after sample collection has been completed.
4. Empty the solvent into each of the fifteen chambers (12 test plus 3 control) without allowing the escape of contaminants from one chamber to another.
5. Maintain a tight seal of each chamber during the period of sample incubation and analysis; this may be as long as a few days but probably not less than fifteen minutes.

Further design criteria require that the valving system have an extremely high probability of functioning properly after the six-month trip, and that it have an extremely low probability of introducing bacteria to Mars. It must also be light weight, small in size, and offer low back pressure to the aerosol stream during sample collection.

The approaches considered for the valving system ranged from those which could valve all chambers simultaneously to those which provide an individual valving system for each chamber; in the latter approach, the multiple valves might be actuated individually or collectively, as desired.

From both size and weight viewpoint, there are strong arguments in favor of a single actuating member that will simultaneously seal off multiple passages. Furthermore, from a reliability viewpoint, there are advantages favoring the valve to be of a non-sliding type. The major disadvantage of such systems is that there is a possibility of leakage between test chambers. The surest way to prevent this leakage is to provide an individual valving system for each separate chamber.

For Concept 1, a single expandible diaphragm was used for sealing off the twelve test chambers after sample collection. Power for actuating the diaphragm was a single explosive charge that served as a gas generator. An additional squib was used for "firing" the solvent from a motor reservoir into the fifteen separate chambers. This system and its advantages and disadvantages are explained on page 12. For Concept 2, a single moving member was used which simultaneously sealed off the twelve test chambers after being actuated. In this case, the moving member closed down upon, and pinched, separate entrance and exit tubes for each chamber. For this Concept, the design objectives included a requirement for individual solvent supplies for each of the fifteen chambers; so the design included fifteen separate reservoirs that could be triggered simultaneously to fill the chambers. Concept 2 had the two major advantages over Concept 1, of providing complete isolation between chambers as well as a separate solvent supply for each chamber. The advantages and disadvantages of Concept 2 are explained on page 17.

Concept 3 also requires separate solvent reservoirs for each chamber as in Concept 2.

Initial studies were along the line of having a single, two step, actuating member that would simultaneously actuate the seals to the dust ports for the twelve test chambers and then follow through to simultaneously fifteen solvent-filled bellows to inject the solution into the chamber. In effect, the design incorporated an individual valving system for each chamber using a common mechanical actuator. Power sources for the actuator considered most seriously were either coiled springs or bellows motors.

The unlatching mechanisms for the stored potential energy of springs seemed to have no greater reliability, for comparable size, than bellows motors. Bellows motors were selected as power sources and it was decided to use several in parallel to gain redundancy. This line of reasoning led to the present design of Concept 3, where a separate bellows motor is used to actuate the valving for each individual chamber. This new design is explained in detail on page 18.

Determination of the Size of the Compressed Bubble in the Reaction Chamber

All of the Multivator concepts considered require that solvent be injected into a sealed, atmosphere-filled reaction chamber. No attempt is made to vent the chamber as it is filled. Instead, the air in the chamber is compressed into a small bubble. We assume that the presence of the bubble will not significantly affect the flourescent light measurements.

The object of this investigation was to determine the size of the residual gas bubble in the reaction chamber. Experimental measurements were taken, and their magnitude verified from theoretical considerations. The experimental apparatus consisted of a 1/16 I.D. plastic tube filled with light oil and the data given below was taken for a range of values of external pressure:

Pressure (mm.Hg)	Bubble Length (in.)	Pressure (psi.)	Bubble Volume (in^3)
18	3.0	.35	.0092
22	2.75	.43	.0084
26 (Martian Atmosphere)	2.50	.50	.0076
31	2.25	.60	.0069
39	2.00	.75	.0061
56	1.75	1.1	.0053
67	1.50	1.3	.0042
94	1.00	1.8	.0031
120	.75	2.3	.0023
760 (Terrestial Atmosphere)	.13	14.7	.0004

The above data is plotted in figure 11.

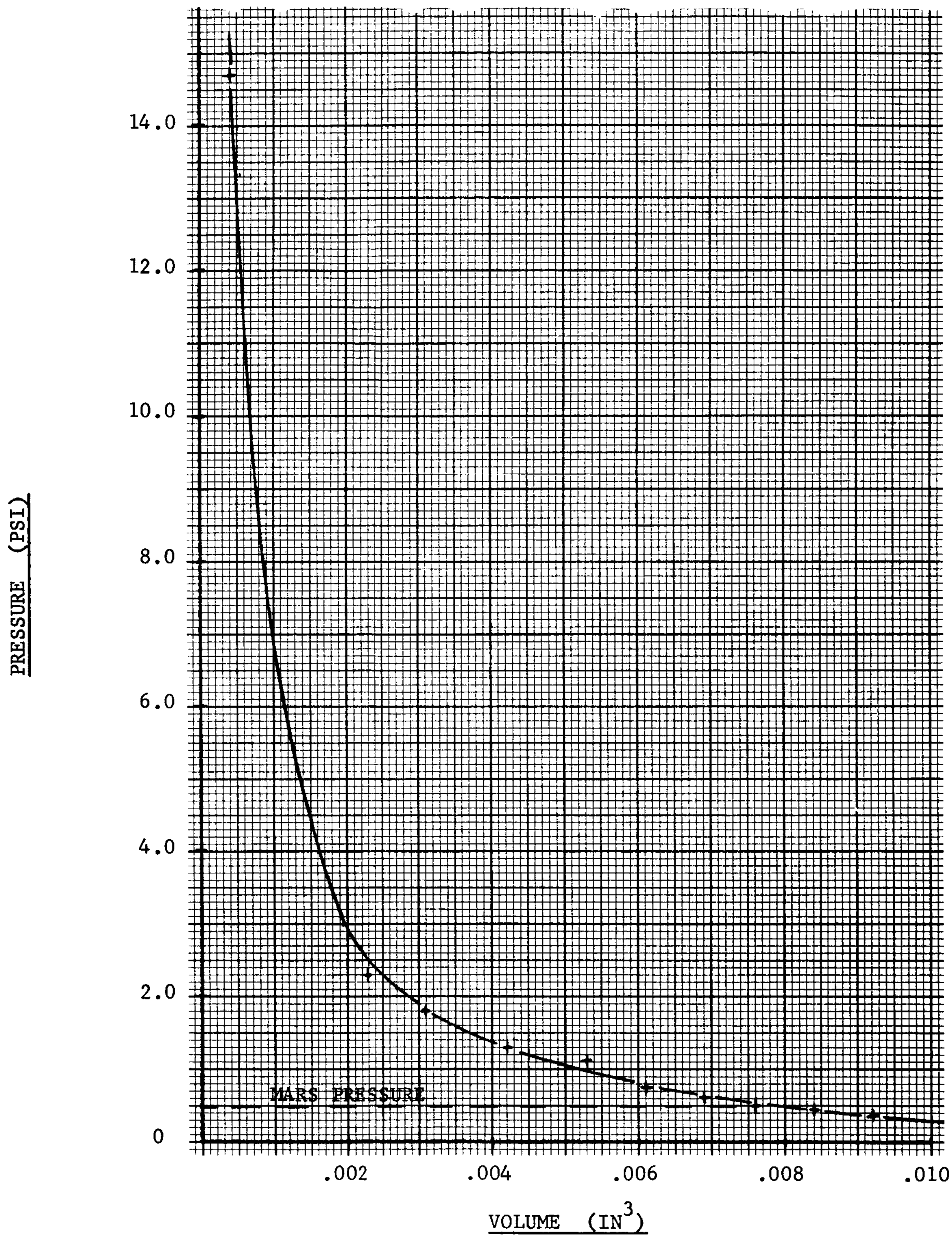


FIGURE 11. EXPERIMENTALLY DETERMINED RELATIONSHIP BETWEEN PRESSURE AND BUBBLE VOLUME

From theoretical considerations we have the following:

If the compression process were adiabatic:

$$PV^k = \text{constant}$$

where P is bubble pressure, V is bubble volume, and k, a constant, is taken to be 1.4, corresponding to a diatomic gas. For bubble pressure $P_1 = 0.5$ psi and $P_2 = 14.7$ psi, we may form the ratio

$$\frac{V_2}{V_1} = \left[\frac{P_1}{P_2}\right]^{\frac{1}{k}}$$

or

$$\frac{V_2}{V_1} = \left[\frac{0.5}{14.7}\right]^{\frac{1}{1.14}} = 0.09$$

The bubble is compressed to 9% of its original volume. If the compression process were isothermal

$$PV = \text{constant}$$

or, forming the appropriate ratio as above

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}$$

or

$$\frac{V_2}{V_1} = \frac{0.5}{14.7} = 0.035$$

The bubble is compressed to 3.5% of its original volume.

Thus the gas bubble in the incubation chamber is reduced to between 3.5% and 9% of its original volume when the pressure is raised from 0.5 psi to 14.7 psi. The compression process is neither adiabatic nor isothermal, but as demonstrated experimentally, somewhere in between because of heat transfer to the environment.

Aerosol Generator

An aerosol generator has been constructed for testing the effectiveness of the dust separator. The device, shown in Figures 12 and 13, consists of a vibrating hopper which drops dust through an orifice into the air stream flowing into the Multivator. The aerosol generator is small enough to be placed inside a bell jar, with the Multivator, during tests at Martian atmospheric pressure.

Advantages and Disadvantages

The impeller dust collection scheme offers several advantages. There are indications that the impeller works well in thin atmosphere since the action primarily consists of impacting particles into the reaction chambers. The impeller may be designed to have a slight pumping action so that it does not present a significant restriction to the aerosol generating device located outside the Multivator. The distribution of particles to each of the reaction chambers is expected to be independent of package orientation since the forces developed by the impeller are much greater than the gravitational forces acting on the particles. Only one valved opening is required in contrast to the other designs which required two openings.

The modular design offers distinct advantages. First, the entire Multivator becomes potentially more reliable with 15 independently operated modules. Second, each of the modules may be filled with different types of solvents, thereby increasing the range of experiments that can be performed with a single Multivator package. The use of explosive charge bellows motors is also advantageous since these are compact, low weight actuators requiring little energy for triggering. It should be noted that the bellows motors do not rely on residual gas pressure to maintain a holding force. Rather, the bellows casing permanently deforms and provides a holding force.

The modular design is expected to result in lower development costs since it is not necessary to build a full complement of modules to evaluate such factors as reliability of the injection mechanism and resistance to physical environment, including sterilization.

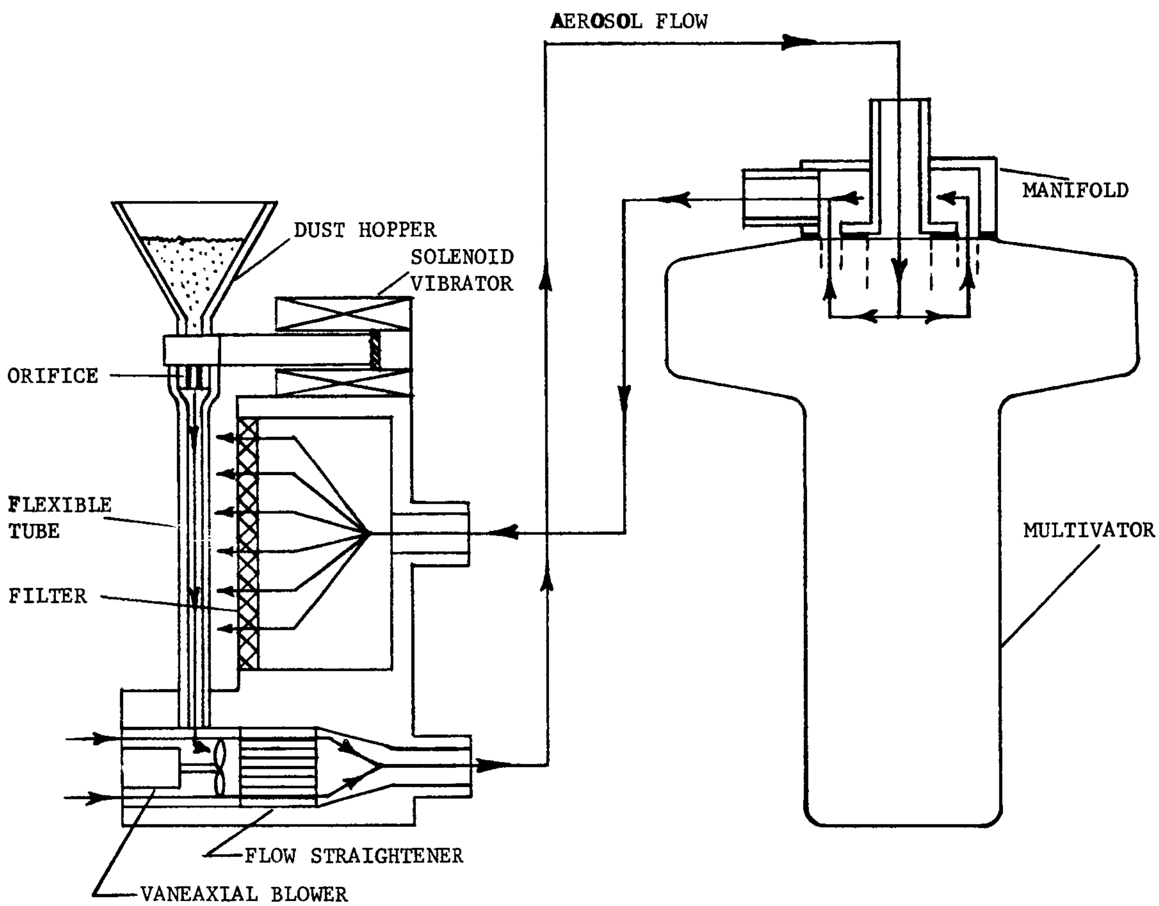


FIGURE 12. SCHEMATIC OF AEROSOL GENERATOR

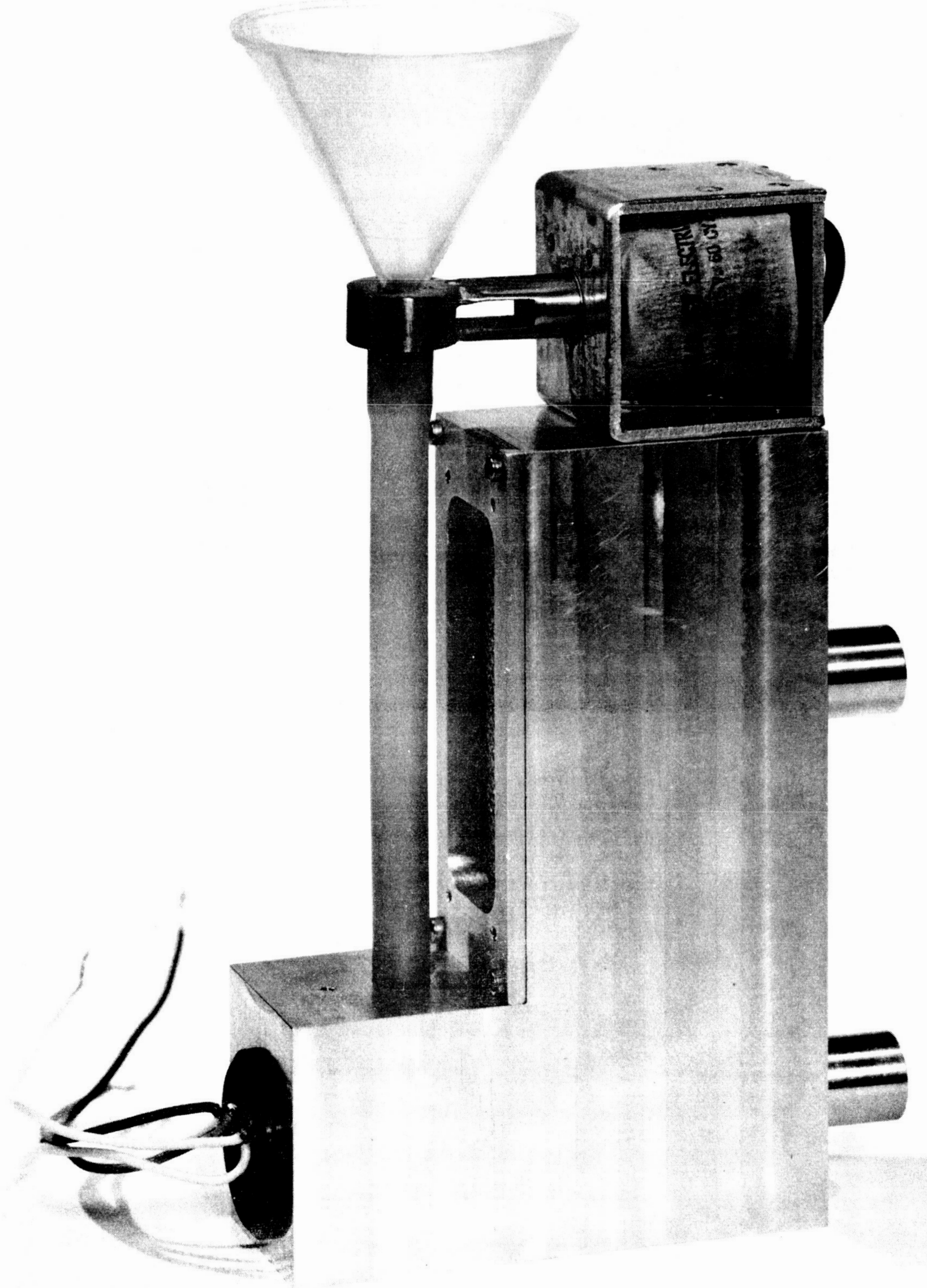


FIGURE 13. AEROSOL GENERATOR

RECOMMENDATIONS FOR FUTURE WORK

Work for the immediate future should essentially consist of perfecting Concept 3. This involves testing of such mechanisms as the dust separator and solvent injector, and examination of reaction chamber materials to determine compatibility with the substrates used.

Perhaps the most important subject of future work will be the examination of all materials used. There are questions regarding the compatibility of these materials with the chemicals and solutions used which are best answered by actual experiment. There are other questions regarding the effect of sterilization and space environment which can be answered by testing and literature study.

The centrifugal dust separator should receive particular attention when planning future work. Further testing of the separator should be done at Martian air pressure using an aerosol stream of known particle size distribution, density, and flow rate.

The search should continue for a sticky material which can be exposed to a space environment, is sterilizable, chemically non-reactive, and soluble. Consideration should also be given to the possibility of retaining dust in the reaction chambers by means of electrostatic attraction.

Some means must be found for ensuring that the correct quantity of dust sample is deposited in the reaction chambers. Too much dust will result in a turbid solution with consequent attenuation of the flourescent light and light scattering in undesirable directions. Too little dust will produce an unreliable reaction. A possible means for controlling the dust collection and deposition period would be based on generating an electrical signal corresponding to the particle concentration of the incoming aerosol stream using the light scattering effect. This signal can be integrated with respect to time and therefore serve as an indication of the amount of dust passed into the reaction chambers.

Testing of the Concept 3 Multivator will very likely lead to refinement of the present mechanical design. For example, there is a possibility that a locking taper on the valve pin can eliminate the spring that keeps the valve seated during solvent injection. Consideration must also be given to providing access to the reaction chambers for installation of the substrate after the Multivator has been assembled and sterilized. Testing of the explosive-charge bellows motors will be necessary in order to determine operating characteristics and verify consistent performance.

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